CALIFORNIA DIVISION OF MINES AND GEOLOGY

Fault Evaluation Report FER-169
Palo Colorado and Sur Fault Zones, Monterey County

by

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April 26, 1985

INTRODUCTION

Potentially active faults in the Point Sur study area of Monterey County that are evaluated in this FER include the Garripato and Palo Colorado segments of the Palo Colorado fault zone and segments of the Sur fault zone (figure 1). The Point Sur study area is located in parts of the Soberanes Point, Mount Carmel, Point Sur, Big Sur, Pfeiffer Point, Lopez Point, Cone Peak, and Cape San Martin 7-1/2 minute quadrangles (figure 1). These faults are evaluated as part of a statewide effort to evaluate faults for recency of activity. Those faults determined to be sufficiently active and well-defined are zoned by the State Geologist as directed by the Alquist-Priolo Special Studies Zones Act (Hart, 1980).

SUMMARY OF AVAILABLE DATA

The Point Sur study area is characterized by compressional tectonics probably related to the San Andreas fault system (Greene and others, 1973). Faults in the study area generally trend northwest and are characterized by high-angle reverse and, locally, strike-slip displacement (Gilbert, 1971; Dibblee, 1973; Clark and others, 1984; Graham and Dickinson, 1978). Many workers have postulated that either the Palo Colorado fault zone or segments of the Sur fault zone connect with the San Gregorio fault zone to the northwest (for example, Graham and Dickinson, 1978; Clark and others, 1984; Greene and others, 1973).

Topography in the study area generally is exceptionally rugged and is indicative of relatively rapid rates of uplift. Consequently, late Quaternary deposits are sparse in the study area and rates of erosion are, no doubt, very high. Therefore, ephemeral geomorphic features formed along active faults may be exceptionally short-lived, especially with respect to reverse faults. Development in the study area is very sparse and mainly is limited to the Big Sur area.

Rock types in the study area include Mesozoic(?) Sur Series metamorphic rocks, Mesozoic granitic rocks, late Mesozoic Franciscan Formation, Late Cretaceous sedimentary rocks, and, locally, late Tertiary Santa Margarita Formation (Dibblee, 1973; Gilbert, 1971; Gilbert, 1973). Late Quaternary deposits generally are limited to marine terrace deposits along the coast, late Pleistocene and Holocene alluvial fan deposits, Holocene river gravels, and colluvium. Landslide deposits are extensive throughout the study area and to date have been only partly mapped.

PALO COLORADO FAULT ZONE

The Palo Colorado fault zone was first described by Trask (1926) as a northwest-trending, approximately 70° northeast-dipping reverse fault with Mesozoic quartz diorite thrust over Cretaceous sandstone. Dibblee (1973) mapped subparallel fault segments considered in this report to comprise the Palo Colorado fault zone (figure 2a). Dibblee mapped the Garripato segment (informally named in this report) of the Palo Colorado fault zone as a right-lateral strike-slip(?) fault and the Palo Colorado segment as a 75° southwest-dipping reverse(?) fault (figure 2a). The Garripato fault may be a northwest extension of the Church Creek fault, a northeast-dipping reverse fault with perhaps as much as 1-1/2 km of dip-slip displacement (Dickinson, 1965). Alternatively, the Garripato fault may continue to the southeast subparallel to the Palo Colorado fault (Dibblee, 1973). The 75°SW dip Dibblee (1973) shows locally along the Palo Colorado fault may be anomalous because elsewhere the fabric of the rocks adjacent to the fault indicate a near vertical to steep northeast dip. In the adjacent Jamesburg quadrangle, Dibblee (1972) shows up-on-the-northeast sense of displacement along the Palo Colorado fault. Both the Garripato and Palo Colorado faults pass beneath and do not offset older (Pleistocene) alluvium mapped by Dibblee (figure 2a). 0.5 to 1 km

Greene and others (1973) and Greene (1977) suggested that the Palo Colorado fault zone may connect with and be a part of the San Gregorio fault zone to the northwest. Greene and others (1973) indicated that a wave-cut platform and, possibly, overlying Pleistocene and Holocene deposits are offset near the Rocky Point-Kasler Point area (figure 2a). However, this offset is based on seismic reflection profiling offshore; no evidence of offset late Quaternary deposits were observed by Greene on shore (H.G. Greene, p.c., 3-19-85).

Buchanan-Banks and others (1978) classified the offshore extension of the Palo Colorado fault zone as Holocene active, based on Greene and others (1973), but classified activity along the on-land fault as unknown (figure 1).

SUR FAULT ZONE

The Sur fault zone is a complex, northwest-trending zone of generally thrust and reverse faults that separate Sur Series metamorphic rocks on the northeast and Franciscan rocks on the southwest (Page, 1970; Gilbert, 1971, 1973). Trask (1926) first described segments of the Sur fault zone as 30°-60° northwest-dipping reverse faults. Page (1970) concluded that the Sur fault zone represents a major subduction zone where deposits of the Franciscan Assemblage were thrust under continental rocks during Cretaceous and early Tertiary time. The style of late Cenozoic displacement along segments of the Sur fault zone includes high-angle reverse faulting and possibly some superimposed strike-slip displacement (Page, 1970). Based on very brief observations, Page stated that topographic features along the Sur fault zone are not directly displaced and that late Quaternary alluvial deposits are not discernably offset.

Dibblee (1973) mapped northwest-trending, generally northeast-dipping reverse faults comprising the Sur fault zone in the study area (figure 2a). A northwest-trending strand of the Sur fault zone, informally referred to in this FER as the Rocky Creek segment, is shown to offset pre-Tertiary granitic and metamorphic rocks. This fault does not offset Pleistocene alluvium near

Rocky Creek (figure 2a). Three other strands of the Sur fault zone are shown to offset middle to upper Miocene sedimentary rocks. Holocene alluvium is not offset along these fault strands. Quaternary deposits are sparse along traces of the Sur fault zone and are generally located along the Big Sur River as isolated terrace deposits. Oakeshott (1951) (figure 2b) mapped Pleistocene terrace deposits uncut by segments of the Sur fault zone in the Pfeiffer-Big Sur State Park region. Although the symbology of Oakeshott's map implies that the terraces are offset, both the cross sections and text of his report clearly state that the terrace deposits are not offset.

Gilbert (1971) mapped an extremely complex fault zone characterized by both northeast-dipping high-angle reverse faults and east-dipping, low-angle thrust faults (figures 2a, 2c). This complex fault zone represents different episodes of faulting, probably since late Cretaceous time. Gilbert stated that low dip angles along many fault segments, sinuosity of fault trends, and the general absence of offset drainages argue against strike-slip offset as a significant component of Plio-Pleistocene deformation along much of the Sur fault zone. However, Gilbert stated that Quaternary strike-slip displacement is possible along the Big Sur (figure 2a) and Gamboa faults (figure 2c). Direct evidence of Plio-Pleistocene deformation along segments of the Sur fault zone in the FER study area was not mentioned by Gilbert. Possibly, Gilbert assumed that significant Plio-Pleistocene displacement has occurred along segments of the Sur fault zone based on the sequence and magnitude of post-Miocene displacement and based on the work of Compton (1966).

Gilbert (1971) did not subdivide late Quaternary deposits in his study area, and it is difficult at times to discern Quaternary-active fault segments. Gilbert shows a possible offset of Quaternary alluvium at locality 8 (figure 2a). However, Gilbert does not discuss this offset alluvium in the accompanying detailed text, and it is assumed that there was a drafting error in the map. Both Oakeshott (1951) and Dibblee (1973) mapped unfaulted Pleistocene terrace deposits at locality 8 (figures 2a, 2b).

Buchanan-Banks and others (1978) classified strands of the Sur fault zone as early Pliocene, but evidence of late Quaternary offset was not observed (figure 1).

Graham and Dickinson (1978) suggested that major post-early Miocene right-lateral strike-slip displacement has occurred along segments of the Sur fault zone (Rocky Creek segment), based on stratigraphic relationships between Franciscan and Miocene sedimentary rocks. They suggest that the Sur fault connects with the San Gregorio fault to the north and postulated that about 115 km of cumulative Neogene right-lateral strike-slip displacement has occurred along the San Gregorio-Sur-Hosgri fault zone. Late-Quaternary slip along the Sur fault zone is not documented in the FER study area (Graham and Dickinson, 1978).

Curry, in a 1984 memorandum to the Monterey Peninsula Water Management District, suggested possible evidence of Holocene activity along the Sur fault zone at locality 1 (figure 2a). A linear sidehill trough, closed depressions, and the large-scale, right-lateral deflection of the Big Sur River are cited by Curry as evidence for recent faulting along the Sur fault zone. Curry suggests that surface fault rupture associated with a M5.0 earthquake occurred along the Sur fault zone. Curry's evidence is based on deformation of the Highway 1 bridge across the Little Sur River (figures 2a, 3). However, no evidence of fault rupture was observed elsewhere along traces of the Sur fault zone. In addition, the January 23, 1984 epicenter is now considered to have occurred just offshore near the Palo Colorado fault, rather than along the Sur fault zone (Lester, 1984; Eaton, 1984).

INTERPRETATION OF AERIAL PHOTOGRAPHS AND FIELD OBSERVATIONS

Aerial photographic interpretation by this writer of faults in the Point Sur study area was accomplished using U.S.D.A. air photos (ABG, 1949, scale 1:20,000). Air photo interpretation was performed mainly to verify fault traces mapped by others, rather than to provide independent mapping. The relatively rapid uplift rates along coastal areas of the Point Sur study area (K. Lajoie, p.c., March 1985), the rapid rates of erosion, and rugged terrain all severely limit the usefulness of evaluating recent reverse and thrust faulting by air photo interpretation. Therefore, the principal emphasis of this photo interpretation was to identify recently active strike-slip faults that may exist in the study area. The few focal plane solutions for earthquakes in the study area generally indicate right-lateral strike-slip offset (Eaton, 1984; Lester, 1984).

Approximately 2-1/2 days were spent in the study area in late March 1985 by this writer in order to verify selected fault segments and to map any subtle features not observable on the aerial photographs. This writer was accompanied in the field by John Kingsley (local consulting geologist) for 1-1/2 days and by Mitch Swanson (local geologist) for 1/2 day.

PALO COLORADO FAULT ZONE

Segments of the Palo Colorado fault zone mapped by Dibblee (1973) (Garripato and Palo Colorado faults) were partly verified by this writer, based on air photo interpretation (figure 2a). These faults are delineated by geomorphic features suggesting Quaternary strike-slip faulting, such as linear drainages, broadly deflected drainages, and alignments of benches and saddles, but geomorphic features indicative of Holocene active faulting were not observed.

There is no geomorphic evidence of late Pleistocene and Holocene offset on the marine terraces at localities 2 and 3 (figure 2a). Well-defined, near-vertical fault zones (some with horizontal striations) were observed in pre-Cenozoic basement rocks at these localities, but the faults did not extend up into the overlying marine terrace deposits. Numerous roadcut exposures of granitic and Sur Series basement rocks indicate that these rocks are extensively sheared, and have a predominantly northwest-trending fabric. An apparent offset in the wavecut platform at locality 2 is less than 1 meter and is probably due to irregularities in the platform surface, probably the result of differential erosion. Irregularities in the wavecut platform are common in this part of the study area and elsewhere in the central California coastal region (Bradley and Griggs, 1976).

The age of the terrace deposits at localities 2 and 3 have not previously been determined. Dibblee (1973) mapped these deposits as Pleistocene in age. The weathering of granitic cobbles and boulders at the base of the terrace deposits and the development of a B soil horizon support a pre-Holocene age. Bradley and Griggs (1976) and Greene (1977) tentatively assigned an age of 70,000 to 125,000 ybp to the lowest emergent terrace north of Santa Cruz, based amino acid dating. However, correlations between marine terraces in Santa Cruz and this study area cannot be made.

SUR FAULT ZONE

Traces of the Sur fault zone mapped by Dibblee (1973) and Gilbert (1971) (Serra Hill, Sur Thrust, Sur Hill Thrust, Rocky Creek, and Aquaje faults) generally are not well defined and are not characterized by geomorphic evidence of late Pleistocene and Holocene faulting (figure 2a). Marine terrace deposits at locality 4, which do not seem to be offset along the Rocky Creek fault, are similar to the terrace deposits described at localities 2 and 3 (figure 2a). Segments of the Big Sur and Gamboa faults locally are delineated by geomorphic features suggesting recent right-lateral strike-slip faulting (figures 2a, 2c, 4). In the Pfeiffer-Big Sur State Park area southeast to locality 1, the Big Sur fault zone is characterized by a sidehill bench, trough, both right- and left-laterally deflected drainages, and a right-laterally deflected ridge (figure 4). Systemmatically right-laterally deflected drainages were not observed, and it is not clear whether the geomorphic features at locality 1 (figures 2a, 4) delineate Holocene faulting. These features align with the Big Sur fault, but the general area is involved with landsliding. The closed depressions are man-modified and are not actually closed, based on interpretation of 1949 U.S.D.A. air photos. The lower trough west of the fault (locality 1, figure 4) is arcuate and is clearly formed by landsliding. The upper trough to the east is also caused by landsliding (figure 4).

Segments of the Gamboa fault (locality 6, figure 2c) have geomorphic features suggesting recent strike-slip faulting. However, evidence of systemmatic Holocene right-lateral offset was not observed by this writer, based on air photo interpretation.

The bridge across the Little Sur River that was damaged during the January 1984 M5.0 earthquake was inspected by this writer in March 1985 (figures 2a, 3). Curry (1984) suggested that deformation of the bridge was caused by surface fault rupture along a segment of the Sur fault zone (Aquaje fault?) (locality 7, figures 2a, 3). However, the deformation was probably caused by shaking associated with the earthquake because: (1) the style of deformation is not consistent with what one would expect from right-slip (no evidence of clockwise rotation); (2) no evidence of right-lateral strike-slip deformation of the asphalt road was observed along the northwest projection of the inferred fault; (3) both the north and south bridge abutments are constructed on fill wedges; (4) there is no geomorphic evidence of recent strike-slip faulting along Curry's inferred fault; and (5) additional evidence of surface fault rupture associated with this event was not observed.

SEISMICITY

Seismicity in the study area is summarized in figure 5. Because most events in figure 5 are C quality, a direct association between earthquakes and specific faults cannot be made. However, segments of both the Palo Colorado and Sur fault zones seem to be seismically active at depth. The M5.0 January 23, 1984 earthquake, orginally located near the Sur fault zone (figure 5), is now considered to have occurred offshore near the Palo Colorado fault zone (Lester, 1984; Eaton, 1984). Focal plane solutions for this event indicate either right-lateral strike-slip offset along a northwest-trending fault, or left-lateral strike-slip offset along an east-west-trending fault.

CONCLUSIONS

The Point Sur study area is characterized by very low developmental pressure, due in part to the extremely rugged terrain of the region. Rates of coastal uplift are anomalously high in the study area as compared with other coastal areas of central California (K. Lajoie, p.c., March 1985). The rapid rates of erosion in the study area and general lack of late Quaternary stratigraphy, render evaluation of surface fault features very difficult, epsecially with respect to faults with significant components of thrust or reverse displacement. It is quite possible that active faults with slip rates on the order of 1 mm/yr would be difficult or impossible to detect in the study area, based on air photo interpretation.

PALO COLORADO FAULT ZONE

Segments of the Palo Colorado fault zone mapped by Dibblee (1973) (Garripato, Palo Colorado faults) were verified by this writer with respect to location, but geomorphic evidence of Holocene strike-slip offset was not observed (figure 2a). Dibblee (1973) mapped Pleistocene alluvium unfaulted by these faults (localities 2, 3, figure 2a). Field observations by this writer indicate that near-vertical, northwest-trending faults in Mesozoic bedrock do not offset marine terrace deposits of pre-Holocene age, based on weathered granitic cobbles and boulders and B soil horizon development (localities 2, 3, figure 2a). A magnitude 5.0 earthquake occurred in January 1984. The epicenter, originally located near the Sur fault zone, has been relocated offshore near the Palo Colorado fault zone (figure 5).

SUR FAULT ZONE

The Sur fault zone is a complex, northwest-trending zone of generally northeast-dipping reverse and east-dipping thrust faults (Gilbert, 1971; Dibblee, 1973) (figure 2a, 2c). Page (1970) indicated that the Sur fault zone represented a major subduction zone during Cretaceous and early Tertiary time. Gilbert (1971) indicated that Quaternary active strike-slip faulting probably has occurred along the Big Sur and Gamboa segments of the Sur fault zone (figures 2a, 2c). However, Quaternary alluvial deposits (where present) are not discernably offset.

Geomorphic evidence of possible late Quaternary strike-slip displacement was observed locally along the Big Sur fault from Pfeiffer-Big Sur State Park southeast to locality 1 (figure 4). Suggestive evidence of recent right-slip is indicated, but it is not certain whether the features are erosional or due to recent faulting. The closed depressions and sidehill bench cited by Curry (1984) as evidence for Holocene faulting at locality 1 (figure 4) are probably formed by landsliding.

Farther south, a segment of the Gamboa fault is moderately well-defined and is delineated by geomorphic features suggestive of Quaternary, but probably not Holocene, strike-slip faulting (locality 6, figure 2c). The lack of late Quaternary deposits, the extremely rapid uplift of this part of the coast, and the many landslides in the area make evaluation of recent faulting very difficult.

It is conceivable that some amount of Holocene surface faulting has occurred along segments of the Sur fault zone (such as the Rocky Creek, Big Sur, and Gamboa faults) and Palo Colorado fault zone, but generally the faults are not well defined. Parts of the Sur and Palo Colorado fault zones are seismically active at depth (figure 5), but the quality of epicenter locations (mostly C) generally precludes the association of specific earthquakes with specific faults. Further studies involving detailed geologic mapping along both the Sur and Palo Colorado fault zones need to be done before it can be demonstrated whether or not Holocene surface fault rupture has occurred along both the Palo Colorado and Sur fault zones.

RECOMMENDATIONS

Recommendations for zoning faults for special studies are based on the criteria of "sufficiently active" and "well-defined" (Hart, 1980). These recommendations are based on reconnaissance level studies and can be changed as new information becomes available.

PALO COLORADO FAULT ZONE

Do not zone for special studies at this time.

SUR FAULT ZONE

Do not zone for special studies at this time.

Reviewed; recommendations approved. Earl W. Hart 5/20/85

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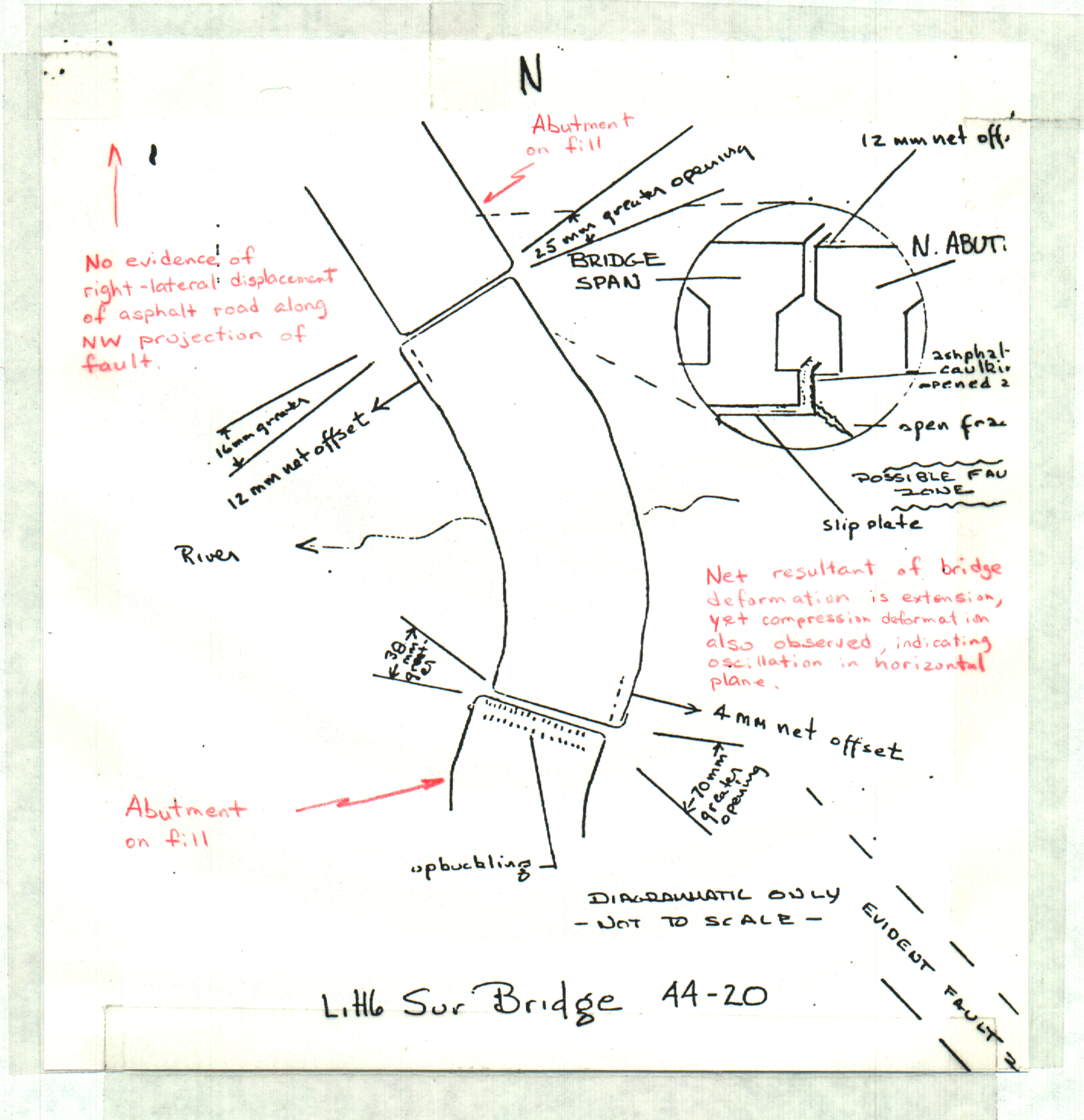

Figure 3 (to FER-169). Deformation of Highway 1 bridge across the Little Sur River observed by Curry (1984). Annotations in red by Bryant (this report), based on field observations in March 1985.

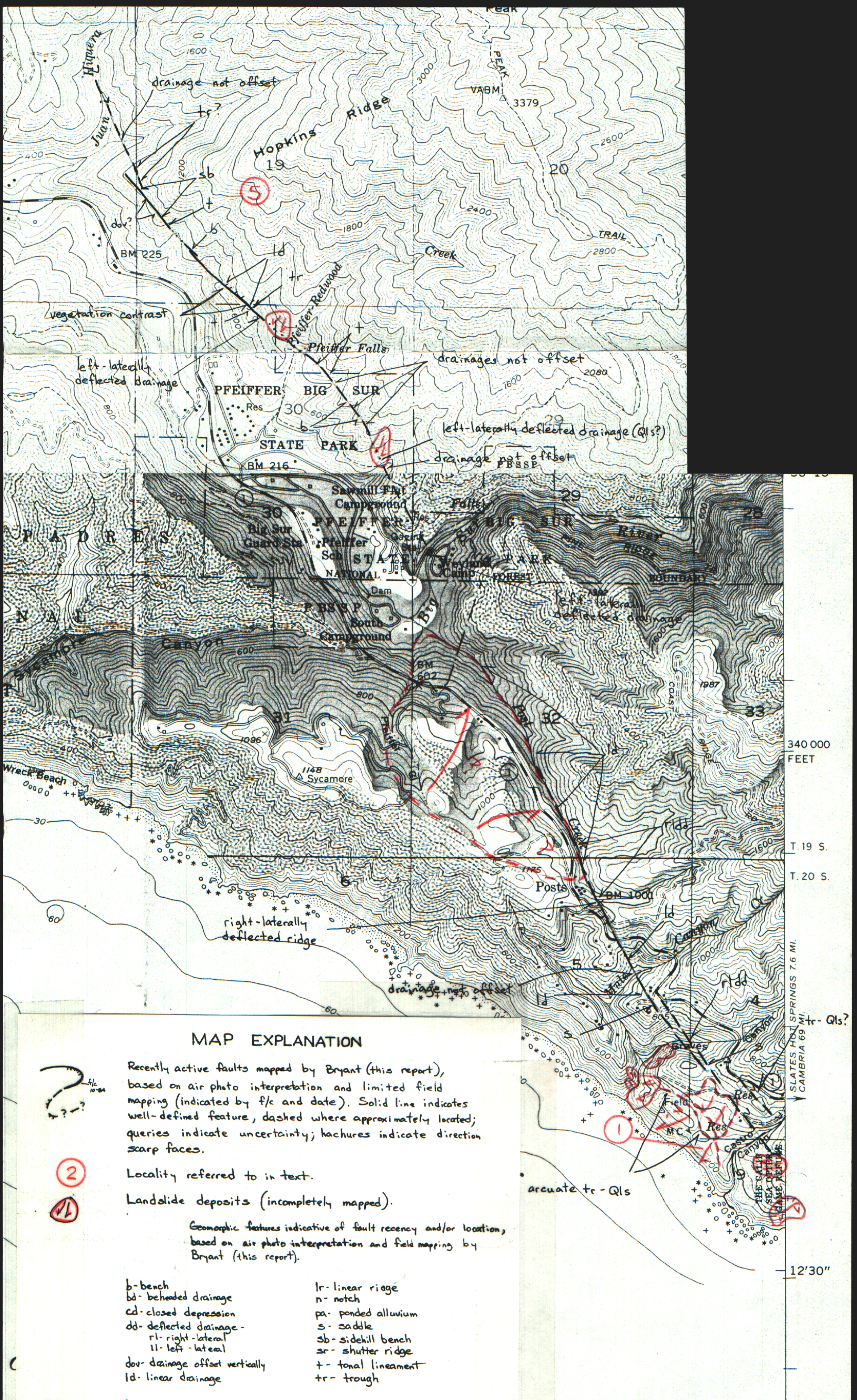

Figure 4 (to FER-169). Recently active faults in the Big Sur and Pfeiffer Point 7.5-minute quadrangles mapped by Bryant (this report).

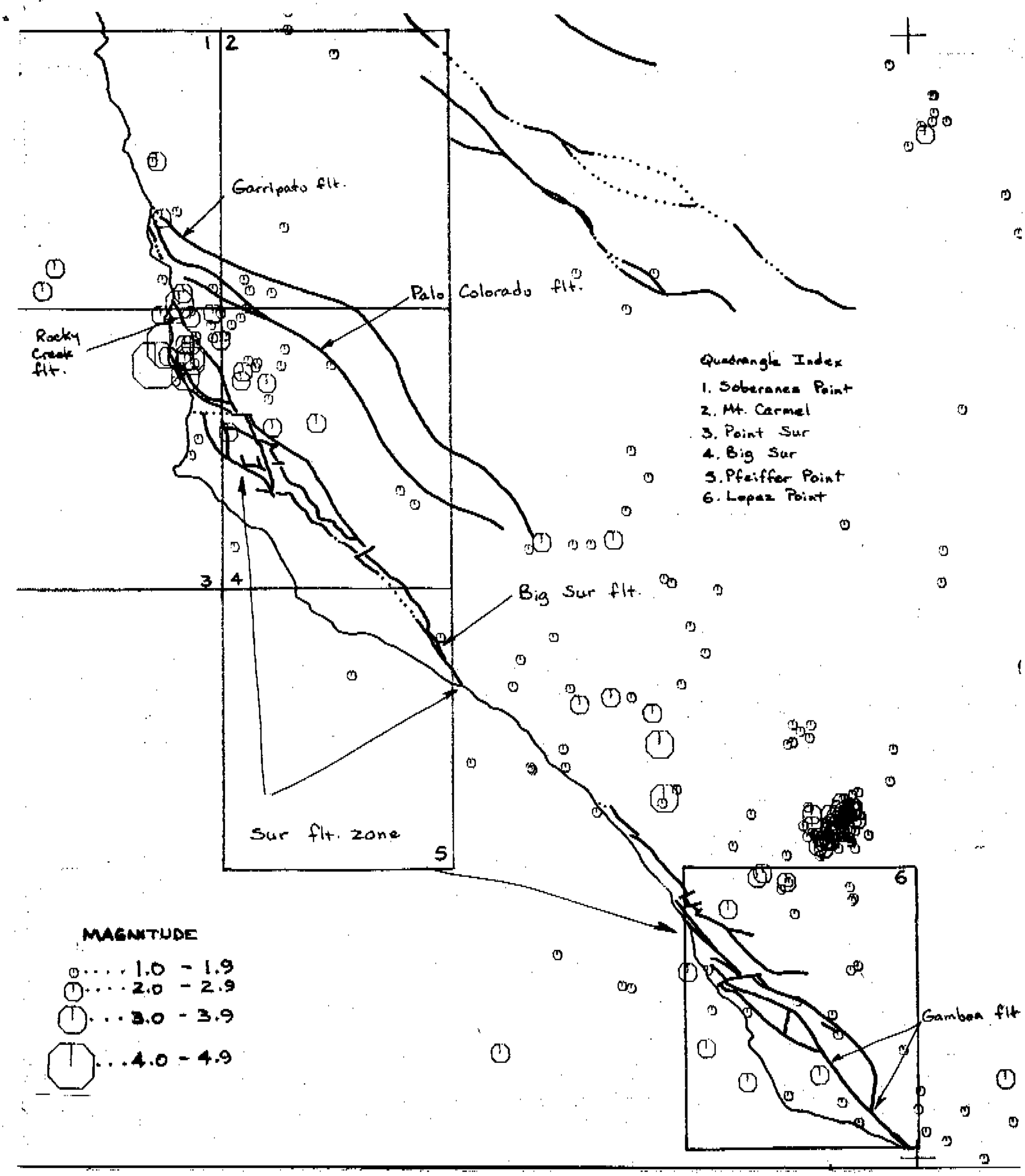

Figure 5 (to FER-169). Seismicity plot for the period 1969-1984 (C quality data) (U.S.G.S., 1985). Faults are from Buchanan-Banks and others (1978).